Quantum Teleportation with Atoms

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Scientists at the University of Innsbruck, Austria, in collaboration with Los Alamos National Laboratory, recently announced the first demonstration of the teleportation of a quantum state from one trapped atom to another located about 10 microns (slightly less than a thousandth of an inch) away. This is the first time teleportation has been achieved with actual particles (as opposed to beams of light) in an entirely deliberate, controllable manner. Related results were also reported by the National Institute of Standards and Technology in Boulder, Colorado.

The key to quantum state teleportation is a fascinating, peculiarly quantum-mechanical link that can be created between two or more particles called entanglement. First studied theoretically by Albert Einstein, together with Boris Podolsky and Nathan Rosen in 1935, entanglement forms the critical ingredient of the futuristic quantum computer, a revolutionary new technology currently under intense development worldwide.

In 1993, an international group of scientists, including IBM's Charles Bennett, proposed a scheme to employ entanglement to teleport the quantum state of one particle to another [1]. At first a theoretical curiosity, within a few years preliminary experiments had demonstrated various aspects of this

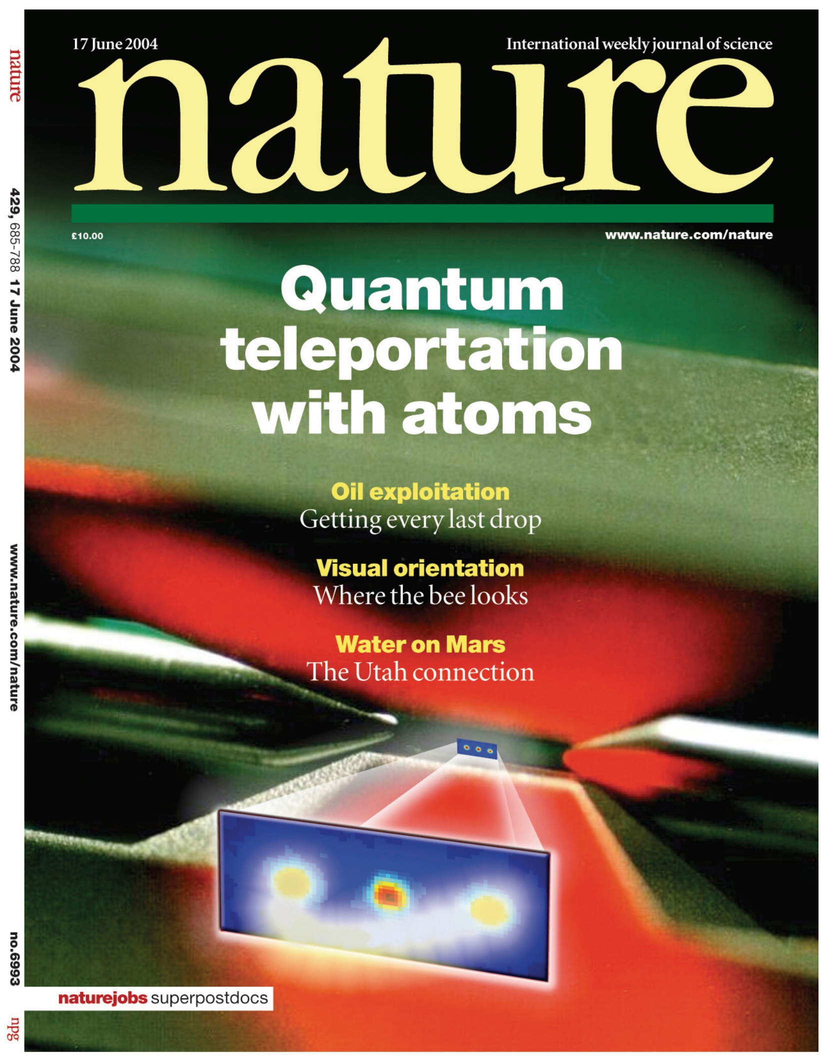

Figure 1— ***The Innsbruck Ion Trap used in the Quantum Teleportation experiment. A CCD image of three ions has been superimposed.***

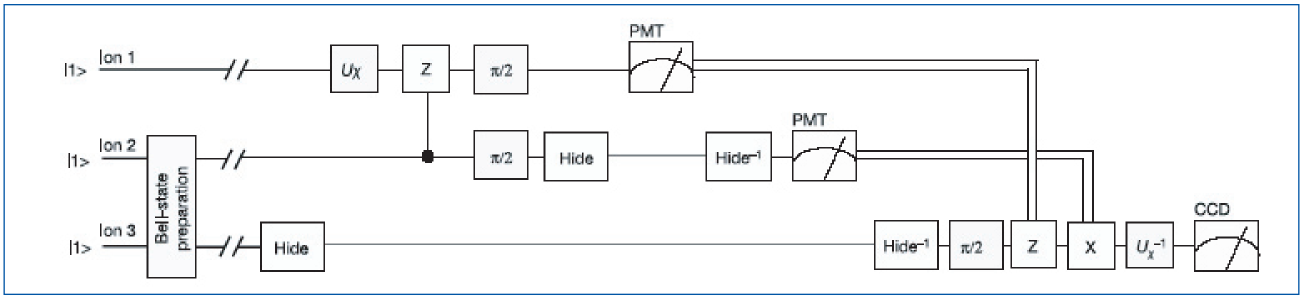

Figure 2—
The quantum circuit executed to carry out the teleportation experiment. The horizontal lines represent the three ions' internal states, the boxes represent quantum gates (carried out using laser pulses) and the boxed semicircles with diagonal lines symbolize a measurement of the ion. The state of ion 1, created by the operation denoted U_χ, is teleported to the lower ion by the creation of an entangled Bell state between ions 2 and 3, a series of operations involving the ions 1 and 2, followed by their measurement, and operations on ion 3 conditional on the result of those measurements.

teleportation protocol. However, it required the development of small-scale prototype quantum computers to perform the operation in its entirety. This has now been done.

In the experiment, described in the June 17, 2004, issue of the scientific journal *Nature* [2], singly-ionized calcium atoms were confined and cooled to ultra-low temperatures (a few millionths of a degree above absolute zero). Using lasers, the internal configurations of the atoms—their quantum states—were controlled very precisely, allowing entanglement between two of the atoms to be created. One of these entangled atoms is then further entangled with a third atom—the input of the teleporter. By performing a simple measurement on this pair, and another series of interactions dependent on the outcome of the measurement, the original input state can be re-created on the remaining (output) atom.

The significance of these results is that they represent a major stride forward towards making quantum information processing a reality. This is a technology that exploits the fundamental properties of quantum mechanical systems—the very properties that make them different from phenomena encountered in everyday life—in order to compute or communicate far more efficiently than is currently possible even with the most advanced supercomputers.

[1] C.H. Bennett, G. Brassard, C. Crepeau, R. Jozsa, A. Peres, and W. Wootters, "Teleporting an Unknown Quantum State via Dual Classical and Einstein-Podolsky-Rosen Channels," *Phys. Rev. Lett.* **70**, 1895–1899 (1993).

[2] M. Riebe, H. Häffner, C.F. Roos, W. Hänsel, J. Benhelm, G.P.T. Lancaster, T.W. Körber, C. Becher, F. Schmidt-Kaler, D.F.V. James, and R. Blatt, "Deterministic Quantum Teleportation with Atoms," *Nature* **429**, 734 (2004).